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Article

An Analysis of Risks and Challenges to the Polish Power Industry in the Year 2024

Stanisław Tokarski [1], Małgorzata Magdziarczyk [2] and Adam Smoliński [1,*]

[1] Central Mining Institute, Plac Gwarkow 1, 40-166 Katowice, Poland; stokarski@gig.eu
[2] Faculty of Economics and Management, Opole University of Technology, ul. Luboszycka 7, 45-036 Opole, Poland; m.magdzirczyk@po.edu.pl
* Correspondence: smolin@gig.katowice.pl; Tel.: +48-259-22-52

Abstract: The green transition is a challenge for the Polish economy and energy sector. In this paper, the expert method of analysis was applied and findings revealed that the challenges and prerequisites for an effective transformation of the power sector mainly include technical, technological and organizational issues of energy production and use. The provision of electricity at competitive prices and with a low carbon footprint, for individual consumers and industry, is a prerequisite for maintaining the well-being of the population and ensuring the competitiveness of domestically produced goods. The ambitious climate policy goals of the European Union require immediate action and call for radical changes in the Polish energy sector; in the coming years, it must drastically reduce the amount of energy produced from fossil fuels and replace it with so-called green energy from renewable sources. The main purpose of this article was to highlight the need to modify Poland's energy policy until 2040 in order to make it more consistent with the ambitious climate goals of the European Union. This article also shows that Poland's energy transition must include a shift from fossil fuels to renewables, while ensuring that energy security is stabilized by the current energy and generation resources. To this end, we discuss the issues of creating reserves in the national energy system for the entire period of Poland's energy transition.

Keywords: energy sector; transformation; energy policy; electricity generation; renewable sources

Citation: Tokarski, S.; Magdziarczyk, M.; Smolinski, A. An Analysis of Risks and Challenges to the Polish Power Industry in the Year 2024. *Energies* **2024**, *17*, 1044. https://doi.org/10.3390/en17051044

Academic Editor: Seung-Hoon Yoo

Received: 1 February 2024
Revised: 16 February 2024
Accepted: 20 February 2024
Published: 22 February 2024

1. Introduction

At the end of 2023, intense work was underway at the European Commission (EC) to finalize the negotiations and final arrangements for the goals, actions and legal tools for implementing the Green Deal [1]. Of importance was the work on finalizing all of the elements involved in implementing the zero-carbon economy that is outlined in the Fit for 55 [2], along with the changes resulting from the REPowerEU [3]. REPowerEU has further clarified the direction of Europe's green transformation, while pointing to the need to become completely independent of fossil fuel supplies [4,5]. Prior to this, in December 2019, the European Commission unequivocally indicated that the directives and regulations implementing the goals of the so-called "Winter Package" [6] (including, in particular, the target related to the reduction of CO_2 emissions by 40% by 2030) are insufficient, and it is necessary to aim for climate neutrality by 2050 instead. Now, the key in the European Union's actions is a new, even more decisive approach to climate change, including mitigation and adaptation measures [7–10]. The Council's work is currently being led by Belgium, which has identified, among its six priorities, the completion of negotiations on regulations implementing the Green Deal, with a strong emphasis, however, on issues related to water quality, the circular economy and sustainable food activities—according to the principle, "from field to table."

Europe's economic policies are strongly influenced by both global and regional political and military events [11–16]. While attempting to rebuild its economy after the COVID-

19 pandemic [14,15,17], Europe also had to fend off the effects of the raw materials crisis [18,19]. Energy raw materials proved to be a powerful weapon in the global competition for supremacy. The issues of security and energy sovereignty of individual countries, as well as the Union as a whole, have returned to the lips of politicians [20]. The changes that have taken place in the world will significantly alter the priorities and understanding of economic and military security. Regardless of cooperation within economic blocs, one's own resources, technologies and goods production chains are becoming more important [21–23]. This will be crucial in the coming years to ensure Europe's independence and sovereignty [24,25]. At the same time, it should be emphasized that the EU does not have significant resources of energy raw materials, or raw materials critical to the energy transition [26,27].

A novel aspect of this article is the identification of directions for Poland's energy transition, which will assist in the achievement of the ambitious climate goals set for Poland as a member of the European Union. The key is to identify new supply chains (photovoltaic panels, electrolyzers for the production of green hydrogen, energy storage, etc.) that will allow Poland not only to catch up with the more advanced EU countries in the context of green transformation, but also to ensure Poland's position among the leaders of energy transformation in Europe.

This article attempts to answer the question of whether the European Union has the chance to gain a leadership position in the economy of the future by being the first economy in the world to switch entirely to carbon-free technologies [28,29]. Our article presents the assumptions of the Polish energy policy until 2040 and points out the need for its modernization. The following sections of this article discuss issues related to the assimilation of energy from weather-dependent sources, as well as options considered for storing energy surpluses. Options related to the use of RES and nuclear power are also presented. Finally, the role of hard coal and lignite in the Polish energy mix is presented. The role of these fossil fuels in stabilizing the energy system is also indicated.

Our approach assumes that Europe's independence from scarce energy resources in favor of renewables is an opportunity to achieve this goal [30,31]. The key to success will be the pace of the transformation, which must be adjusted to the possibility of Poland rebuilding its own production chains (photovoltaic panels, batteries, electrolyzers, etc.) [32,33]. At the same time, it should be pointed out that the transformation process must be secured, in the first phase, by using the raw material resources of the old continent. This will ensure security and eliminate the specter of an energy crisis that could be caused by energy shortages resulting from a military blockade of hydrocarbon transport to Europe.

The decarbonization of the energy sector, and the economy as a whole, is expected to accelerate significantly in Polish politics and its economy at the beginning of 2024. Therefore, at the end of 2023, Poland received its first funds from the EU in the amount of EUR 5 billion, as part of the implementation of projects covered by the RepowerEU program [5,28]. These funds are to be used primarily to support investments in renewable energy sources and electricity grids. This is the first step that will precede the government's efforts to revise energy policies and the country's commitments to contribute to European climate goals. In this policy debate, there will be inherent issues such as the increased assimilation of renewable energy from RES sources by the national system, identifying a realistic date for the construction of the first nuclear power plant and the question of coal and gas demand during Poland's energy transition.

2. Materials and Methods

Assumptions of the Polish Energy Policy

Poland's energy policy until 2040 (PEP2040) [34] was adopted in February 2021, but quickly became obsolete. In December 2020, the European Council adopted the Green Deal and the goal of climate neutrality by 2050, with an intermediate target of a 55% reduction in greenhouse gas emissions by 2030 relative to emissions in 1990, while Poland's

Energy Policy to 2040 included the European greenhouse gas reduction target of 40%, and Polish ambitions were set at 30% in the National Energy and Climate Plan (NECP) [35]. This situation changed due to a resource crisis. Natural gas—which, according to Poland's Energy Policy until 2040, was to serve as a transition fuel for power and heating—proved too risky in terms of its availability and price. Poland, lacking sufficient quantities of gas, was forced to import it, which entailed high costs and risks related to the timely supply of the resource. In view of the above, as well as assessing the progress of investment projects in offshore wind farms and nuclear power, the Government decided in April 2022 to adjust Poland's energy policy. In mid-2023, in a pre-consultation formula, the so-called Scenario No. 3 to Poland's Energy Policy was presented, which set energy mix targets by the year 2040, assuming that 73% of the electricity would come from renewable sources, which would correspond to 74% of the share of the renewable capacity installed in the national system. Comparing the simulations to the capacity from the current Energy Policy of Poland until 2040 (the high allowance price scenario) with Scenario No. 3, it is easy to see that the capacity of the NPS in 2040 differs by more than 100% (an increase from 60 GW to almost 130 GW). This is shown in Figure 1.

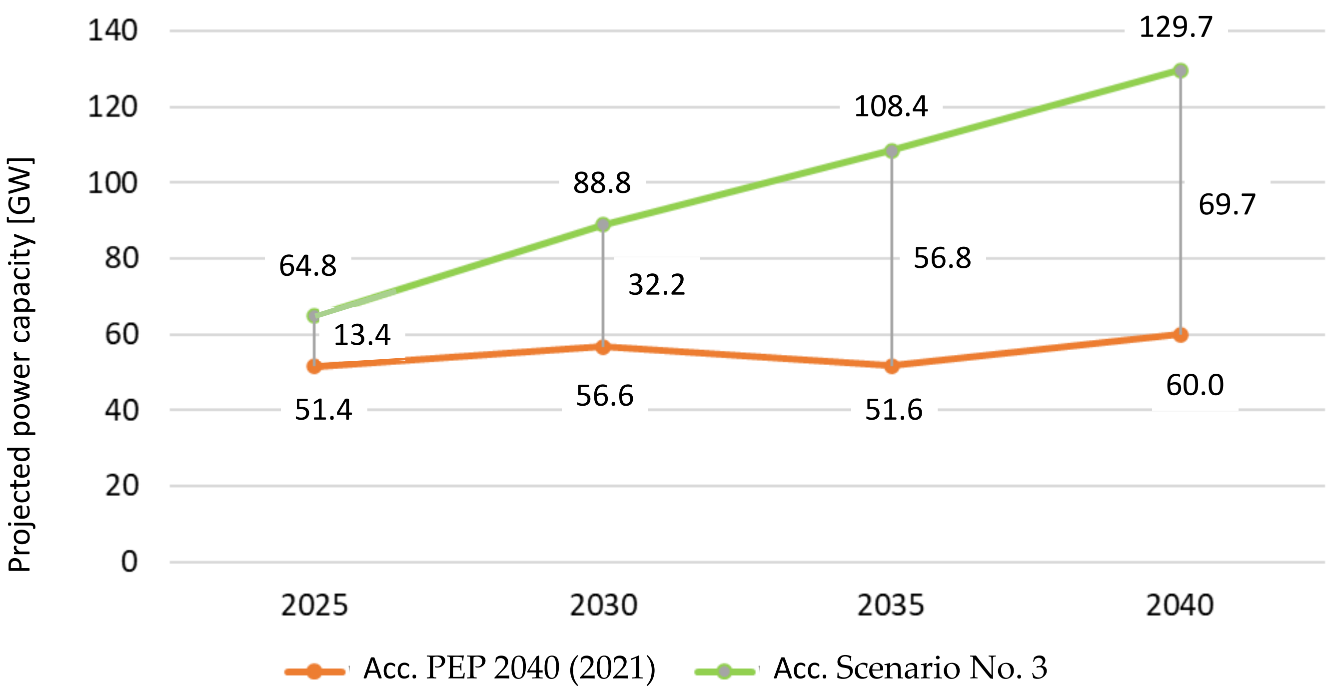


Figure 1. Projected size and structure of NPS power in 2040 according to the current 2021 PEP 2040 and Scenario No. 3, without the 2023 revision [36].

The forecast of electricity consumption is analogous. In the current policy, the volume of domestic consumption is assumed to be 204 TWh in 2040, while in Scenario No. 3, the forecast is 244 TWh. The comparison is shown in Figure 2.

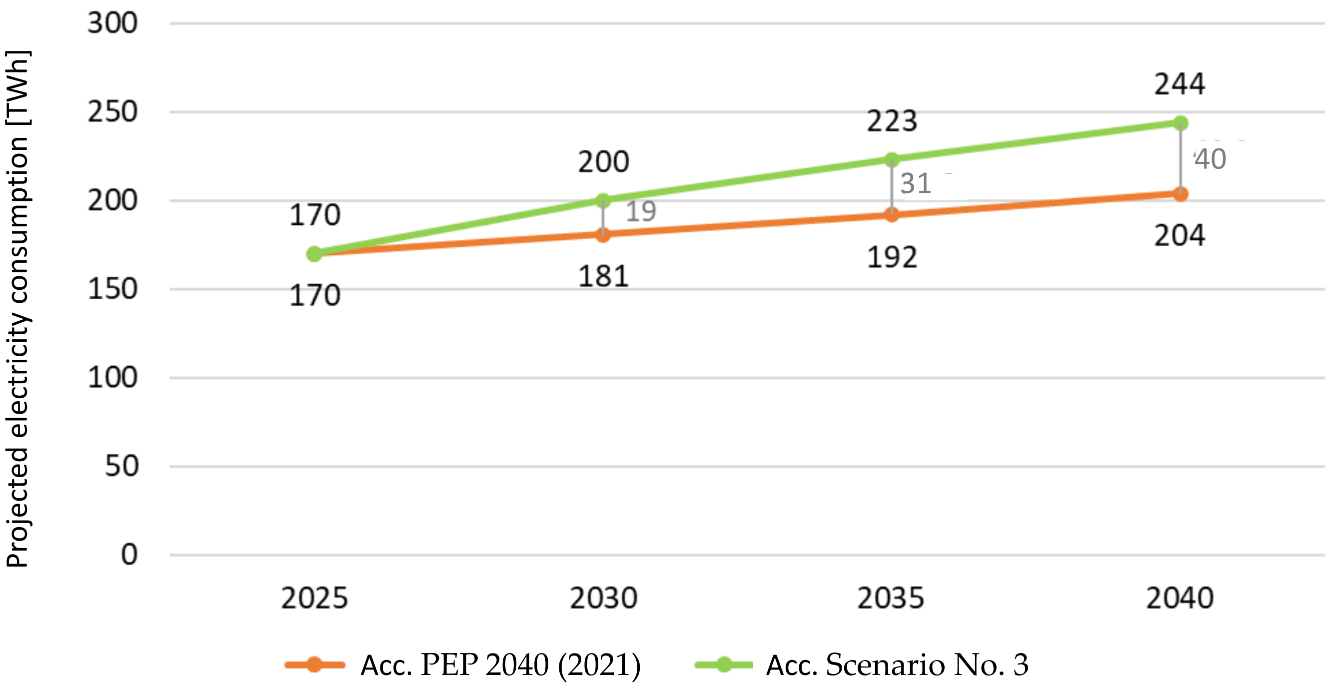


Figure 2. Electricity consumption forecast with structure until 2040 according to the current PEP 2040 and Scenario No. 3 [36].

Attempting to redefine the country's energy mix will require a robust "feasibility study" of the ability to rebuild generation sources and the electricity transmission and distribution system; then, realistic Polish climate targets can be defined. The European 2030 emission reduction target for the ETS sector is 62%, relative to the reference year (2005). Translating this target directly into the domestic energy sector would require a reduction in greenhouse gas emissions of almost 30 million tons over the period of 2024–2030. Therefore, Poland's new energy policy must take into account both the "ambition" of the reconstruction of the national mix, as well as the reality of the pace of the implementation. However, such a change should be preceded by a solid study of the entire economy, taking into account changing external conditions, including the experience of the Ukrainian conflict.

The scientific approach to forecasting Is based on a number of forecasting methods and ways of classifying them. One of the basic divisions is between quantitative and qualitative methods. Quantitative methods are based primarily on predictive models built using available statistical data. Qualitative (heuristic) methods are based on the judgments of experts (individuals or groups of experts). In forecasting based on these qualitative methods, we are not dealing with a formal model, but primarily with a mental model. Such models include: the survey method, the method of successive approximations and the Delphi method. In our study, a heuristic method was used for data analysis. The authors prepared the questionnaire and collected the opinions of 80 experts from the energy sector, universities and industrial energy consumers. The collected data were analyzed using the Delphi method.

3. Results and Discussion

The transformation of Poland's electricity system towards non-carbon energy requires, on the one hand, an accelerated investment in renewable sources, and, on the other hand, fully insuring this process by securing the country's own controllable generation sources. From the 2030 perspective in Poland, these are almost exclusively coal-fired power plants. Domestic power companies (PGE, Tauron, Enea, Energa) which have decided to implement, among other things, large wind projects, have encountered a barrier to financing new investments from the banking sector, due to their possession of coal-fired power plants in their assets. The separation of coal assets from concerns became a condition for obtaining further investment financing in the European market (this condition, and in particular, the manner of its implementation, needs to be verified from the current perspective). In 2022, the Polish Government adopted the document "Transformation of the Electricity Sector in Poland." [37], which stipulated the establishment of the National Agency for Energy Security (NABE). The NABE became tasked with taking over all coal-fired power plants and lignite mines from state-owned companies. The purpose of establishing the NABE was to create a reserve of regulatory power for the NPS for the transition period, to free the power companies from coal assets, to create a new entity for the restructuring/liquidation of power plants and to increase Poland's energy sovereignty.

Assuming that the establishment of the NABE will enable the creation of a regulatory power reserve for the NPS for the transition period, it will become necessary to separate power units that will be launched outside the energy market by the Polish Power Grid (PSE), which will not participate in the energy market due to excessive costs and limited operation time. Among the main assumptions of the NABE changes, issues related to the disposition of power units are pointed out first and foremost. Namely, power units will be commissioned by the PSE outside the energy market rather than as a participant in the market, mainly due to high costs and limited operating time. In addition, it is assumed that the NABE's financing system should include three main elements: transmission fee, funds from the strategic reserve (fixed costs) and revenues from energy sales (variable costs). The assumed model of the NABE's operation also includes mines, but those that are technologically related to the power plants are included in the NABE.

The NABE project has not been implemented to date. At this stage, however, it requires an adjustment which should result in a significant reduction in the State's financial involvement in the process (the size of the Treasury's guarantee at PLN 70 billion in the first year, according to the current draft). Another key factor will be the absence of payments for the transfer of coal assets between State Treasury companies. Adjusted to actual needs, the size of the NABE should also reduce the need for working capital, including covering the purchase of emission allowances.

3.1. Assimilation of Energy from Weather-Dependent Sources

The dynamics of the investment in renewable sources, especially in distributed photovoltaic installations, led for the first time to a situation where the system operator in Poland decided in April 2023 to limit the production of solar farms, to ensure the safety of its operation [38]. The supply of electricity from domestic sources was higher than the demand for it from both national and foreign consumers. In such situations, there must be a reduction in the supply. Since it is necessary to maximize the amount of renewable energy in the energy mix, the key is to increase its assimilation by the NPS. However, this requires consideration of the following measures, such as energy storage and demand flexibility (including dynamic tariffs to ensure local balancing).

3.1.1. Energy Storage

In terms of energy storage, pumped storage plants (ESPs) are the most efficient large-scale electricity storage facilities. The Polish power system has about 1.9 GW of ESP installed capacity and the ability to store about 9 GWh of electricity (the energy produced, for example, by a 1 GW wind farm in 9 h). The Government plans to build about 2.5 GW of pumped storage capacity, mainly in three locations: Młoty, Tolkmicko and Rożnów. The construction of such energy storage facilities may not take place until after 2030. It should, therefore, be concluded that the energy storage capacity of the ESP will remain small and will not increase the assimilation of energy from "weather-dependent" sources by the NPS.

Battery-based, large-scale energy storage appeared for the first time in last year's main auction for 2027, in the amount of only 165 MW, with the possibility of storing less than 0.7 GWh. It should be pointed out that the settlement price of last year's auction was a record high, amounting to more than 406 PLN/kW/year. The formula for the operation of energy storage in the power market allows participation in the energy market and system services, but the restrictions are so significant that investors chose not to conclude more contracts. In the general certification, more than 16 GW of energy storage was reported in the 2023 auction (deliveries for 2028). The price obtained in 2023, according to the PSE's announcement, was PLN 244.90; 40% less than a year ago. As a result of the auction, 1.7 GW of energy storage capacity was finally contracted, which should be considered a very good result. The potential increase in the volume of renewable energy in the daily balance is less than 7 GWh. The low price of the power obligation in the resolved 17-year contracts until 2044 means that investors have adopted business assumptions indicating a different future formula for the operation of storage facilities in the European market than the current one, which will assure the profitability of their investments.

Prosumer energy storage facilities are not very popular in Poland. It is estimated that there are about 10,000 of them, with a capacity of about 100 MW. The main reason for this is the principle of mandatory balancing of energy injected by the prosumer by the national system (net metering principle), which is in force until 2023. The change of this rule to net billing in 2023, as well as subsidies for the purchase of energy storage under the next "My Electricity" program, may change prosumers' approaches to investing in their own storage facilities. According to the author, such a distributed system can significantly flatten the daily curve of the electricity demand in the system without significant grid investment. If 1 million prosumers install home storage, it is possible to achieve a storage capacity of as much as several GWh of energy, which, with intelligent programming of charging cycles and use of power for home use or in organized local groups, can contribute to both increasing the amount of renewable energy in the grid and reducing energy consumption during peak hours.

Hydrogen produced by electrolysis, using excess electricity from renewable sources, could be an efficient way to store energy in the future. However, the relatively low efficiency of this process should be emphasized. Thus, as long as renewable energy is still a scarce commodity in the national system, such a form of storage should be considered only for surplus energy, i.e., energy that cannot be used at a given time, and its production would have to be reduced. The European Commission's Delegated Act of July 2023 [39] introduced the principle of the simultaneity of energy production in renewable sources with the electrolysis process that produces hydrogen. In addition, these sources must not be older than three years from the date of production of the first kilogram of hydrogen. This restriction means that hydrogen produced using renewable energy excess from older sources is not considered to be green. Hydrogen produced in this way can be used to generate electricity again, using a variety of technologies.

In conclusion, the potential for electricity storage in the national power system is insufficient and is not expected to increase significantly by 2030.

3.1.2. Elasticity of Demand

Flexible demand, or the use of electricity when it is in excess and at lower prices, serves to increase the volume of renewable energy in the national system. The 28 July 2023 amendment to the Energy Law, which came into effect on 7 September [40], introduces a demand flexibility service, which can be contractually concluded between the local distribution network operator and the customer. The customer may give up a part of their power (flexible power) and the supplier will be entitled to exercise such a right of curtailment during peak hours. The detailed rules and method of remuneration for giving up a part of the power, and consequently the energy supplied to the plant or household, have not been defined. However, following the example of the US market, the right of the local operator to turn off, for example, air conditioning or heating at the customer's site, for a certain period of time, may be associated with a discount in their electricity bill.

As of 24 August 2024, electricity sellers in Poland will be required to offer dynamic tariffs to their customers. Dynamic tariffs mean offering electricity at a price that changes over time, depending on the availability of energy in the national system. The customer will be able to decide whether to increase consumption when there is availability and a lower price, and whether to reduce consumption during peak hours. At the same time, the risk of receiving a large bill when using energy in high price zones will fall on the consumer. Making dynamic tariffs available to residential consumers requires the installation of real-time meters at consumers' premises, and the construction of a central energy market information system (CSIRE), as well as systems that actively manage consumption.

Local generation and use of renewable energy is the most efficient way to increase renewable energy in the structure of the national mix. Supporting the creation of local communities that generate electricity with its storage and efficient use can significantly reduce the need for investment in distribution networks. It is technically and economically inefficient to transform energy from the low-voltage level in order to send it to a relatively close-by point in the system at medium voltage.

3.2. Nuclear Energy

In the second half of 2023, "essential location decisions" were issued in Poland for the first two large-scale nuclear power plants in Lubiatow–Kopalin and Konin. The issuance of an essential location decision means that the investment is in line with the public interest and state policy. It begins with the lengthy process of obtaining the necessary further approvals and decisions, a construction permit and, following this, the start of construction itself. The first nuclear project in Poland will be carried out by a consortium of Westinghouse Electric Company and Polskie Elektrownie Jądrowe. Construction at Lubiatów–Kopalin is expected to begin in 2026. The current Polish energy policy until 2040 sets the commissioning date for the first nuclear unit by 2033. Based on the actual realization cycle of 1000 MW-class coal-fired units in Poland in the previous decade, the time from the start of the bidding process, with the assurance of the ability to finance the project, to the production of the first MWh, could be expected to take 10 years. Given that, in addition to determining the location and identifying the technology, there is no financing model, including a support mechanism (e.g., a contract for difference), a capital structure of the implementation company or a procurement formula (a tender, direct supply from the technology supplier); therefore, it is expected that the commissioning date of the first nuclear power plant will be delayed further.

The 1920s saw the expansion of the idea of small modular reactors (SMR) [41,42]. The main advantages of SMRs are compactness, built-in, passive safety systems and the possibility of scaling the output power, thus reducing investment costs. Technologically, small reactors use the same principles as their large counterparts. The most advanced project of the US company NuScale, whose physical implementation began in Idaho, was unexpectedly stopped in the second half of 2023. A lack of economic efficiency was cited as the reason. In Poland, cooperation with NuScale was led by KGHM, which, after announcing the decision to discontinue its first-of-a-kind investment in Idaho, communicated the opening of their project to other suppliers. A remaining competitor of NuScale's project was GE Hitachi's BWRX 300 reactor project. The company's first reactor project is currently under construction in Ontario, Canada, with a plan for commissioning by 2030. In Poland, an agreement to cooperate on the construction of another project has been signed by Orlen Synthos Green Energy. In December 2023, Poland's Minister of Climate and Environment issued in-principle location decisions for six projects across the country. BWRX 300 reactors use a different technology for steam generation to the turbine than PWRs (like large reactors, or NuScale). In boiling BWR-type reactors, radioactive steam is fed directly to the turbine. The concept of building distributed units in urban centers, as announced in the location decisions, has prompted the discussion of site considerations and will probably intensify such discussion, considering the technological and nuclear safety issues. In addition, BWR technology is not indicated in the current program for nuclear power and is not being developed in Europe. There has been an increase in interest in small reactors by "nuclear" countries and companies in recent times, but the lack of a commercially implemented first civilian solution in the world dictates restraint in forecasting the date of commissioning such a unit in Poland.

3.3. Hard Coal and Lignite in the National Energy Mix

In 2022, as much as 77% of electricity was generated from coal. Half of the 175.2 TWh which was generated in that year came from coal-fired power plants. More than 40 million Mg of hard coal was used for this purpose. The domestic mining industry mined 42.1 million Mg of this raw material and imported 17.2 million Mg of thermal coal. The year 2022 was a special year in the world economy due to the intensification of activities directed at importing coal from outside Europe. As a result, enough coal and gas were imported for the needs of the domestic economy. However, an undesirable consequence of these actions turns out to be the stockpiles of expensive thermal coal (estimated at about 8 million Mg), left over from the siphoning off from coarse assortments necessary for households, which remained after late deliveries in the spring of 2023.

In 2023, the PSE's preliminary figures show a decline in production to 163.6 TWh (down by 6.58%) and electricity consumption to 167.5 TWh (down by 3.44%) in Poland. Coal-fired power generation also fell to a 68% share of the mix, with hard coal accounting for 76.6 TWh. The expected hard coal output in 2023 is about 37 million Mg, while imports will be approx. 18 million Mg.

In the energy mix, the share of coal is gradually declining. However, in the national balance in winter, in the absence of solar generation, approx. 20 GW of thermal power plant capacity is needed to ensure system balancing.

The key, therefore, is to determine the minimum necessary electricity production in conventional units during the transition period. In an expert study conducted at GIG in 2021 (Transformation, 2021), a demand curve was produced for hard coal until 2040; this is shown in Figure 3. Hard coal consumption for electricity generation, according to this research, will fall to about 15.8 million Mg in 2040; a value slightly higher than the PEP 2040 forecast (the high allowance price scenario) or 11.1 million Mg. In Scenario No. 3, from mid-2023, the demand for lignite is projected to fall to virtually zero by 2040, and for hard coal to 10 million Mg. The projection of the use of gas for electricity generation until 2040, adopted in Scenario No. 3, assumes the maximum use of gas for electricity generation in 2035, in the amount of 7.6 billion m. In 2030, the use of 5.9 billion m of gas is projected, which means the possibility of generating about 30 TWh of electricity.

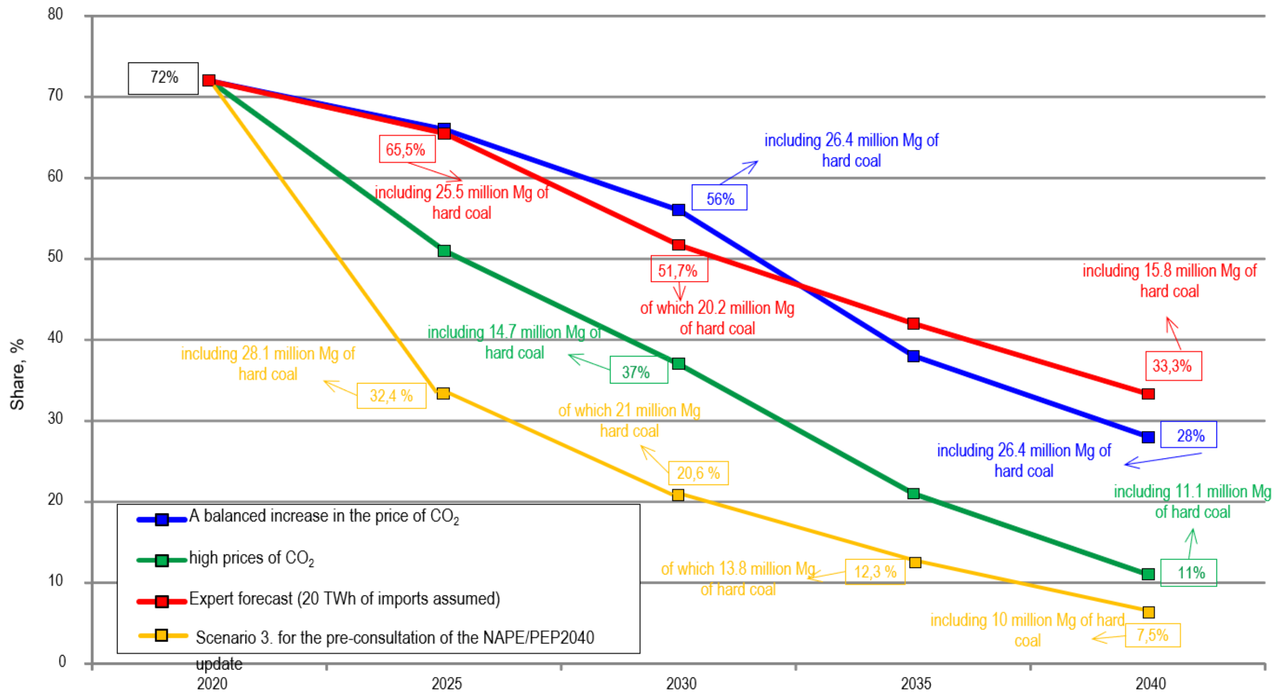
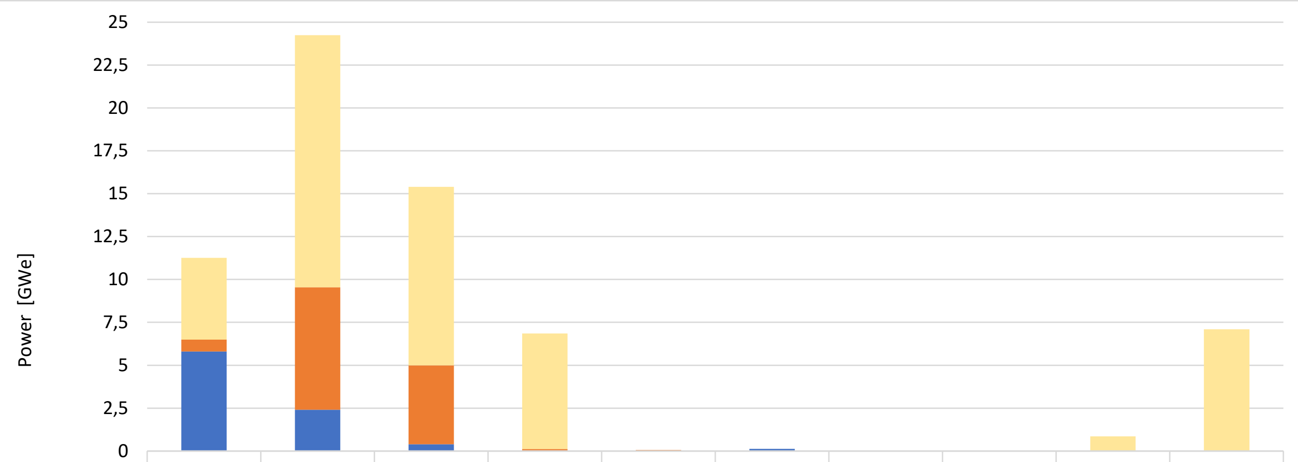


Figure 3. Projected share of hard coal in the national energy mix. PEP 2040, Scenario No. 3 and results of an expert study in 2021.

Figure 4 shows the structure of the power mix that has been contracted as a result of the capacity market auction until 2027. No new gas-fired capacity was contracted in the December 2023 auction. It follows from this structure that about 5.8 GW of new gas-fired capacity will be added to the national system between now and 2030. The total installed capacity based on gaseous fuels will thus exceed the figure of 11 GW by 2030.

It is crucial to point to coal or gas as a key fuel during this transition. It is assumed that after 2030, the capacity installed on gas can practically cover the demand curve of the national system for most of the year.



	Natural gas	Hard coal	lignite	Hydro	Biomass	PV	wind	energy storage	foreign units	DSR
Units in use	4,76	14,7	10,4	6,74	0	0	0	0	0,85	7,1
upgrades	0,7	7,14	4,6	0,11	0,06	0	0	0	0	0
New units	5,8	2,4	0,4	0	0	0,12	0,02	0,02	0	0

Figure 4. The mix of capacity contracted in capacity market auctions. Source: unpublished materials from TGPE presentation in 2023.

4. Conclusions

The challenges and prerequisites for the effective transformation of the electricity sector mostly involve technical, technological and organizational issues of energy production and use. Providing electricity at competitive prices and with a low carbon footprint for individual consumers and industry alike is a prerequisite for maintaining the welfare of the population and ensuring the competitiveness of domestically produced goods. For this purpose, it is necessary to consider the issues of energy trade and the rules of price creation in the market, as well as the intervention of the State in periods of economic fluctuations and crises.

1. An analysis of the necessary measures to transition the national energy mix away from fossil fuels should ensure the security of this complex and long-term process. This security should be based on the energy and generation resources at hand. What is needed, therefore, is a reserve of the national energy system for the transition period, organized in the NABE, which will be a power supplier and disposed of by the PSE.
2. It has been shown that investment in renewable sources, including civic energy, should be accelerated at the most reasonable pace. The key issue remains to increase the scope of assimilation of energy from weather-dependent sources by the national system, taking into account aspects of storage and flexible demand. Excessive investments, from which energy will not be able to be used, should become a source of “stranded costs” for which all energy consumers will pay.
3. Nuclear power is desirable in the Polish reality to ensure a non-carbon mix in the perspective of 2040. Experience in the implementation of large-scale projects, especially in new, in national conditions, technologies dictate great caution in planning the availability of this energy in the national mix. Electricity from the first nuclear power plant is likely to be yielded closer to 2040. Small modular reactors will not significantly accelerate this date.
4. By 2030, efficient coal-fired power plants will determine the operational security of the national system, as well as the volume of electricity produced. After 2030, electricity from offshore wind farms and gas-fired power plants will determine the mix. Coal-fired power plants will act as a power supplier and operate mostly outside the energy market. A market play between gas fuel and coal is possible.
5. It is not possible to design a national mix on a year-by-year basis, which would turn out to be valid in a few years. It should be assumed that in 2040, practically one hundred percent of non-carbon energy is possible in the national mix, in technologies that will compete with each other, outlining a “hard” power curve and production capacity in controllable technologies that are disposable by the system operator (coal, gas). These resources will insure the system and generate energy only at absolutely necessary times.
6. The share of hard coal of 10–12 million Mg in 2040 in the national mix is possible. When designing a path for the transformation of hard coal mining, it is necessary to assume the maintenance of such mining capacity as an absolute reserve for the system. Regardless, in the event of favorable coal prices on world markets, it will also be possible to import this fuel economically.
7. The heuristic methods used here have limitations pertaining to the quality of the experts’ selections and their experiences. However, in a very volatile process, as energy transformation is, these methods are needed to support the data and actions based on formal, mathematical models. The implications of the study presented in this paper result in urgent correction of the Polish energy policy, especially caused by a delay in the national nuclear program. Lack of zero-emission electricity from nuclear power plants in the perspective of 2033 in the energy system, generates a risk of shortages of power in Poland.

Author Contributions: Conceptualization, S.T., M.M. and A.S.; methodology, S.T., M.M. and A.S.; formal analysis, S.T., M.M. and A.S.; investigation, S.T., M.M. and A.S.; writing—original draft

preparation, S.T. and A.S..; writing—review and editing, S.T. and A.S.; visualization, S.T.; supervision, A.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data will be available on request.

Conflicts of Interest: The authors declare no conflicts of interest.

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